

Operation of cable lines under fire conditions

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Abstract. Branched cable communications are carriers of fire load, they are tracks along which fire spreads in buildings and structures. Therefore, currently, fire safety of cables is one of the most important tasks of the cable industry. The spread of flames in vertical bunch wiring depends on the following factors: the amount of combustible material that is exposed to high temperatures, geometric shapes of cables and their mutual location when laying, the ignition temperature of gases emitted by cables, the volume of combustible gases emitted by cables at a certain elevated temperature, the room capacity and volume of air passing through the cable structure, cable devices. Analysis of regulatory documents revealed some key differences in the methodology of standards. It was found that the spread of fire is not only affected by the volume of laid cables, but also by their mutual placement in space. A direct correlation was found between the influence of the cross-section of the cable core and preservation of the cable line in case of fire. Parameters were determined for the preservation of serviceability under fire exposure in the case of bunch and in the case of single wiring. It has been determined that it is impossible to spread the results of fire tests in case of single wiring in accordance with GOST IEC 60331-21-2011 and in case of bunch wiring in accordance with GOST IEC 60332-3-22-2011 to the results of tests in accordance with GOST R 53316-2009 for the preservation of operability of cable lines. The parameters of fire resistance and operability of cable products under the influence of flame depending on the type of cables and the method of their installation have been determined.

1 Introduction

Fire safety of cable lines must be considered as a complex set of different factors. Cables have a very complex multi-component design that combines combustible materials (electrical insulation, cable sheathing, etc.) and internal heat sources - electrically heated conductive cores, which in emergency modes of operation can become sources of fire and provoke fire development [1-3].

Analysis of statistical data shows that the causes of 20-25% of fires annually occurring in Russia are related to the operation of electrical installations. The same ratio is typical for

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many industrially developed countries of Europe. According to the statistics, this is the cause of about 50 000 fires, the direct damage amounts to ~ 1.5 billion Russian rubles annually, without taking into account indirect losses from underproduction, interruptions of power supply and insufficient supply of electric power. The same statistics show that the largest number of fires (over 60%) in the operation of electrical installations is connected with cables and wires.

Branched cable communications are not only carriers of fire loads, but also tracks on which the fire can spread over buildings and structures. For this reason, at the moment, providing fire safety for cables is one of the most important tasks of the cable industry.

Fire-resistant cable lines (FRCL) are relatively new in use. Previously, cable insulation was performed on the basis of mica, glass fabrics, basalt thread, etc. The high price of such cables was due to the complexity of design and manufacturing technology.

Cables with high fire safety have insulation, filling or sheathing (sometimes all together) of special PVC plastic, which has an increased oxide index and reduced smoke formation. This type of cables generates a much smaller amount of toxic and corrosive hydrogen chloride compared to traditional formulations. Currently, new generation cables are in great demand in industrial and residential construction, transport and oil and gas industry. In recent years, the production of cables using polymer compositions that do not contain halogens has been expanding, which corresponds to global trends. In the future, cables of this type will replace those containing polyvinylchloride plastics. Especially important is the use of these cables in the underground, and a new series of power and control cables, including medium voltage power cables (10 kV), was developed based on the requirements of Moscow Metro.

Cable lines are used in firefighting systems where long-term service under high temperature conditions is required. Cables with increased fire safety are used in systems of detection, warning and control of emergency evacuation of people and ensuring the work of fire protection units in case of fire [4-8].

In conditions of intensive technological progress, production facilities and sites have emerged, in which hi-tech systems are used and many people are present, and this demanded the increase of reliability of systems, providing safety of people, also in conditions of fire hazard. Functioning of fire systems could only be provided with fireproof cables [9-12]. The appearance of new normative base also stimulated this process. So in 2003 GOST R IEC 60331-21-2003 "Tests of electric and optical cables in the conditions of influence of a flame" was put into operation, the accepted norms of fire safety obliged designers to provide system of evacuation of people so that it could keep working during the time interval necessary for full evacuation of people from a dangerous zone.

The main regulatory document for now is the Federal Law № 123 "Technical Regulations on Fire Safety Requirements", namely Article 82 "Cable lines and electrical wiring of fire protection systems, means of ensuring the activities of fire protection units, fire detection systems, warning and evacuation of people in a fire, emergency lighting on evacuation routes, emergency ventilation and smoke protection, automatic fire extinguishing, internal fire water supply, elevators for transportation of fire protection units in buildings and constructions must remain operable in fire conditions during the time necessary to perform their functions and evacuate people to the safe zone [13-17]. Besides, requirements to cable lines are made according to GOST R 53316-2009 "Cable lines. Preservation of operability in fire conditions".

According to statistics, in Russia in 2018 as a result of emergency modes in cable products there were 25698 fires (64,2% - to the number of fires from electrical installations), which caused direct damage of 3471698 thousand rubles (80%); the number of fatalities was 773 people (41,3%). The greatest number of fires from cable products occurs in the residential sector, where the greatest number of deaths was also recorded.

Table 1. Statistics on deaths in fires caused by cable products.

Facilities	Number of fires	Direct damage, thousand roubles	Death toll, people
Industrial	1366	1717557	18
Retail	1232	234446	1
Residential	18338	1134560	738
Agricultural	148	26038	3
Administrative and public buildings	607	91259	1
Buildings under construction	126	5339	0
Outdoors storage areas	62	9429	0
Transport	3489	235967	9

It has been established that burning polymer compositions produce suffocating and poisonous substances such as carbon monoxide, nitrogen oxide, hydrogen sulfide, hydrogen chloride, formaldehyde and several other compounds, which, if inhaled, may provoke respiratory tract disorders or cause death [18-20]. Particularly dangerous is carbon oxide, which is formed by burning almost all materials and in most cases is the cause of casualties in fires.

When polymeric insulation compositions and cable sheaths are destroyed and burned, gaseous substances such as chlorine, bromine, fluorine, sulfur dioxide and others are released, which, when combined with water vapors, form acids or alkalis are capable of causing corrosion of metal structures and corrosion damage to electronic equipment. Although the corrosive dynamics of combustion products itself does not have a significant impact on the formation of fire, one should take this factor into account when designing cables, since the corrosive destruction of steel structures and equipment generates collateral damage from fire, which is significantly higher than the price of burned cables.

A general requirement for cables intended for laying in cable structures is non-proliferation of combustion. This is one of the most important characteristics of the cable, indicating the ability of the cable to stop burning independently after removing the ignition source. At the same time, there are requirements for non-proliferation of combustion for a single cable sample and requirements for nonproliferation of combustion for bunch wiring.

Cables with increased fire safety are cable systems that include trays-crops, perforated and non-perforated, wire trays, wall and ceiling hangers, cantilever brackets, mounting profiles, studs, anchors, fasteners, as well as many auxiliary devices to all types of products with a certain fire resistance limit.

For fire-resistant cables either single or bunched wiring is used (several units in a line) [6]. The selection of the method of laying is determined by the type of fire-resistant cable lines themselves, as well as the features of the project.

The use of cables that meet the requirement for non-proliferation of combustion for a single sample, in bunch wiring may lead to the spread of flame through the cables. This is because flame propagation in vertical bunch wiring depends on a number of factors:

- The amount of combustible material that is exposed to high temperatures, as well as flames generated by burning cables;
- the geometric shapes of cables and their mutual location when laying;
- ignition temperatures of gases emitted by the cables;
- the volume of combustible gases released by cables at a certain elevated temperature;
- room capacity and the volume of air passing through the cable structure.

It was found that the spread of fire is affected not only by the volume of cables laid, but also by their mutual placement in space. As an example Figure 1 shows that five cables of general industrial version of the type VVG and NRG, in most cases, spread the combustion at the vertical location of samples. In this case, a steady spread of combustion is observed when the cables are located in a bundle with a gap, as shown in Figure 1. In this regard, all modern types of cables that do not spread combustion in the bunch (non-combustible version) are tested in the bundles with a normal volume of combustible materials (the number of cables) with or without a gap, depending on the types of cables and the characteristic method of laying them in cable structures.

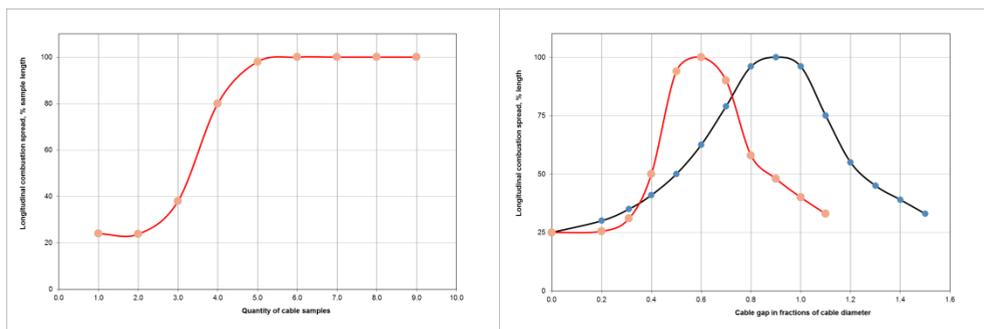


Fig. 1. Dependence of combustion spread.

In accordance with [3], cables for nonproliferation of combustion in bundles are subdivided into 5 categories depending on the normalized mass volume of non-metallic structural elements. The most stringent standards are established for cables in test category A and AF/R, for which the normalized volume of combustible materials is 7 liters per 1 meter of cable bundle. Typically, in Russia, these requirements are set for cables for energy purposes (power, control and management). For other types of cables less stringent standards may be set, which are defined in the test categories of samples with a mass of combustible materials of 3.5 l/m (category B) or 1.5 l/m (category C).

In electrical installations where there are special fire safety requirements, it may be important to use special types of cables.

The use of cables that do not meet the requirements of standards to curb their ability to spread combustion, should be limited to small sections to connect devices to permanent wiring and in any case should not be allowed between rooms separated by fire walls.

Wiring components, except cables that do not meet the requirements of standards to curb their ability to spread combustion, but in all other aspects meet the requirements of standards, are to be placed in a shell of fireproof materials.

When installing FRCL a variety of mounts and fasteners are used. In the installation of fiberglass on the basis of trays and stair trays wall brackets are used.

In an open single and bunch wiring as part of the FRCL can be connected without using a cable tray - on single brackets and clamps that are attached to the walls.

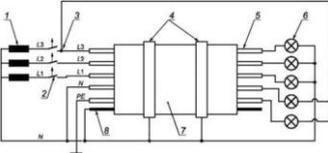
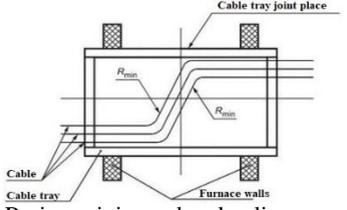
Cable brackets are designed for laying and fixing cables and installing pipelines for industrial use indoors and outdoors.

Cable clamps are designed for laying single cables and cable bundles to the walls and floor.

Cable clips are designed for wall and ceiling paired and single wiring on flat surfaces. They allow you to complement the FRCL with cables of different cross sections.

Analysis of regulatory documents (GOST IEC 60331-21-2011 and GOST R 53316-2009), has revealed some key differences in methods and final results of tests. This comparative analysis is presented in Table 2.

Table 2. Comparative analysis of normative documents.

<p>GOST</p> <p>Characteristics</p>	<p>GOST IEC 60331-21-2011 Testing of electrical and optical cables under conditions of flame exposure. Retaining operability.</p>	<p>GOST R 53316-2009 Cable lines. Maintaining operability in fire conditions. Test method</p>
<p>Application field</p>	<p>The standard applies to low voltage power cables, management and control cables.</p>	<p>The standard only applies to cable lines that are subject to fire resistance requirements and specifies the test method.</p>
<p>Method of specimen attachment during testing</p>	<p>A single cable is fixed with a screw with a ring in increments of ~50cm.</p>	<p>Cable suspension system for bunch wiring consists of a galvanized wire mesh twisted with hexagonal Manier cells.</p>
<p>Type of test bench</p>	 <p>1 - transformer; 2 - fuse (2 A); 3 - phase connection; 4 - supporting rings; 5 - test lead or group of leads; 6 - load indicator device (e.g. lamp); 7 - sample; 8 - metal screen.</p>	 <p>R_{min} - minimum bend radius, mm, determined in accordance with the technical documentation for the cable.</p>
<p>Test duration</p>	<p>The total duration of the test includes the time of exposure to the flame (according to the regulatory document for a particular cable) and a cooling period of 15 minutes (the sample remains energized).</p>	<p>The test shall be carried out within the time specified in the technical documentation for this specimen.</p>
<p>Test protocol</p>	<p>Test protocol 1) detailed description of the cable under test; 2) name of the manufacturer of the cable under test; 3) test voltage; 4) any deviations during the test from the requirements of this standard; 5) criteria for evaluation of test results applied factually (with reference to Section 7 or the regulatory document for a particular cable); 6) flame exposure time.</p>	<p>Not regulated by GOST</p>

The purpose of the study is to determine the possibility of extending the results of tests for fire resistance of cables at single wiring according to GOST IEC 60331-21-2011 and at bunch wiring according to GOST IEC 60332-3-22-2011 to the results of tests according to GOST R 53316-2009 to maintaining the operability of cable lines.

Tasks of research:

1. Evaluate fire resistance of cable in accordance with GOST IEC 60331-21-2011 "Tests of electrical and optical cables under the influence of flame". Evaluation of fire resistance of vertically located bunch wiring in accordance with GOST IEC 60332-3-22-2011 "Tests of electrical and optical cables under the influence of flame".

2. Determine the performance of cable lines (FRCL) and the integrity of FRCL fasteners GOST R 53316-2009 "Cable lines. Preservation of serviceability under fire conditions. Method of testing".

3. Determine the influence of cable core cross-section on maintaining operability of cable lines under fire exposure.

4. Analyse influence of the number of cable samples at single orbunch wiring under fire exposure.

2 Methods

Determination of the limit state of cables was carried out according to GOST IEC 60331-21-2011 "Testing of electrical and optical cables under the influence of flames. Preservation of operability. Part 21: Testing of electrical and optical cables under flame conditions. Testing performance and requirements to them. Cables for rated voltage up to 0.6/1.0 kV inclusive".

For tests power cable type VVGng(A)-FRLS was taken, which is fireproof. In addition to fire resistance, it has a reduced fire hazard and reduced smoke - and gas emission. It consists of copper wire conductor core, mica tape winding, polyvinyl chloride insulation with reduced fire hazard, inner and outer sheathing of PVC with low gas-smoke emission. Appearance of cable samples is shown in Figure 2:



Fig. 2. Appearance of the cable sample VVGng(A) - FRLS 3*10 before the tests.

Determination of the serviceability of cable lines (FRCL) and the integrity of FRCL fasteners was conducted in accordance with GOST R 53316-2009 "Cable lines. Preservation of serviceability in fire conditions. Method of testing". Tests are carried out in a small-size furnace for testing building structures for fire resistance.

Cable laying was carried out on the furnace wall. At single wiring the cable is fastened with a screw with a ring with a pitch of 50 ± 5 cm.

Bunch wiring consisted of 8 groups of cables, for 3 groups cables were selected with the same section and a different number of cores, for 3 groups cables were selected with the same number of cores and a different cross section, 2 groups are a combination of cables with different cross sections and numbers of cores. Cable suspension system for group cabling consists of metal trays, fixed with perforated tape and studs.

Determination of fire resistance of the cable was carried out according to GOST IEC 60331-21-2011 "Testing of electrical and optical cables under the influence of flames. Maintaining operability. Testing of electrical and optical cables under the influence of flame.

Part 21. Testing performance and requirements to them. Cables for rated voltage up to 0.6/1.0 kV inclusive".

3 Research results

Fire Resistance Tests in accordance with IEC 60331-21-2011 State Standard

The results of fire tests on cable samples are given in Table 3.

Table 3. Test results.

Sample type	Duration of fire exposure, min.	Circuit breaker actuation time, min.	Distraction time of conducting core, min.
VVG non-combustible(A) - FRLS 3*1,5	75	-	-
VVG non-combustible(A) - FRLS 3*10	75	-	-

The appearance of the cable sample after test is shown in Figure 3:



Fig. 3. Appearance of VVG non-combustible(A) - FRLS 3*10 cable sample after test.

As a result of the fire effect on cable samples mica-containing steel windings became very viscous and as a result, the cable in the area of the flame became sticky.

Cable samples VVGnon-combustible(A) - FRLS 3*1,5 and VVGnon-combustible(A) - FRLS 3*10 kept working during the set time of 90 minutes in the test conditions as:

- voltage was applied to the cable samples during the whole test, i.e. the fuse did not burn out;
- the conductive core was not damaged, i.e. the lamp was not extinguished.

Evaluation of noncombustion of vertically located bunch wiring in accordance with GOST IEC 60332-3-22-2011

Vertically arranged mounted cable samples are shown in Figure 4. 1 group: VVG non-combustible(A) - FRLS 3*1,5, VVGnon-combustible(A) - FRLS 3*10; 2 group: VVGnon-combustible(A)-5*10, VVGnon-combustible(A)-3*4, VVGnon-combustible(A)-3*1,5; group 3 (left): VVGnon-combustible(A)-1*10, VVGnon-combustible(A)-3*10, VVGnon-combustible(A)-5*4, VVGnon-combustible(A)-5*1,5.



Fig. 4. Appearance of cable samples before test.

Testing of samples was carried out in accordance with the requirements of GOST IEC 60332-3-22-2011 "Testing of electrical and optical cables under the influence of flames. Part 3-22. Spreading flame along vertically arranged bundles of wires or cables. Category A".

The results of flame propagation tests on vertically arranged cable bundles are presented in Table 4.

Table 4. Flame propagation test results on vertically arranged cable bundles.

Wiring group	Cable category	Cable typr	Means of fastening	Number of layers and pieces in each layer	Flame exposure time, min	Number of burners	Length of damaged part, m	Independent burning or smouldering time, min
1	A	VVG non-combustible(A) - FRLS 3*1,5	With a gap of 3 cm	1 layer – 1 piece	40	1	1,39	1,2
		VVG non-combustible(A) - FRLS 3*10			40	1	1,34	1,1
2	A	VVG non-combustible(A) - LS 3*1,5	Without a gap	2 layers – 1 piece	40	1	1,27	-
		VVG non-combustible(A) - LS 3*4			40	1	1,33	
		VVG non-combustible(A) - LS 5*10			40	1	1,17	
3	A	VVG non-combustible(A) - LS 5*1,5	Without a gap	2 layers – 1 piece	40	1	1,39	-
		VVG non-combustible(A) - LS 5*4			40	1	1,31	
		VVG non-combustible(A) - LS 3*10			40	1	1,44	
		VVG non-combustible(A) - LS 1*10			40	1	1,53	

1) cable line (top part): VVG non-combustible(A) - FRLS 3*1,5 is fixed in three places by means of perforated tape;

2) cable line: VVGnon-combustible(A) - FRLS 3*10 is fixed in three places by means of a punched tape;

3) group of cable lines: VVGnon-combustible(A) - FRLS 3*1,5 - 2pcs, VVGng(A) - FRLS 3*10 - 2pcs are laid in a tray 8x8cm, which is fixed in three places by means of studs;

4) group of cable lines with structural protection (ceramic fiber): VVGnon-combustible(A) - LS 3*1,5, VVGnon-combustible(A) - LS 3*4, VVGnon-combustible(A) - LS 3*10, VVGnon-combustible(A) - LS 5*1,5, VVGnon-combustible(A) - LS 5*4, VVGnon-combustible(A) - LS 5*10 are stacked in a tray 5x30cm which is fixed in three places by means of studs and the punched tape;

5) group of cable lines without structural protection: VVGnon-combustible(A) - LS 3*1,5, VVGnon-combustible(A) - LS 3*4, VVGnon-combustible(A) - LS 3*10, VVGnon-combustible(A) - LS 5*1,5, VVGnon-combustible(A) - LS 5*4, VVGnon-combustible(A) - LS 5*10 - are stacked in a tray 8*8cm which is fixed in three places by means of studs.

Life time of each cable line is presented in Table 5.

Table 5. Test results.

№	Cable	Wiring group	Temperature, °C	№ indicator	CL performance time, sec
1	VVGnon-combustible(A) - FRLS 3*1,5	1	840	1	650
2	VVGnon-combustible(A) - FRLS 3*10	2	840	11	1628
3	VVGnon-combustible(A) - FRLS 3*1,5	3	840	21	717
4	VVGnon-combustible(A) - FRLS 3*1,5		840	31	565
5	VVGnon-combustible(A) - FRLS 3*10		840	2	1736
6	VVGnon-combustible(A) - FRLS 3*10		840	12	2004
7	VVGnon-combustible(A) - LS 5*1,5		840	4	837
8	VVGnon-combustible(A) - LS 1*10	4	840	27	847
9	VVGnon-combustible(A) - LS 3*4		840	23	875
10	VVGnon-combustible(A) - LS 5*4		840	3	881
11	VVGnon-combustible(A) - LS 3*1,5		840	22	742

№	Cable	Wiring group	Temperature, °C	№ indicator	CL performance time, sec
12	VVGnon-combustible(A) - LS 3*10	5	840	13	1137
13	VVGnon-combustible(A) - LS 5*10		840	24	1202
14	VVGnon-combustible(A) - LS 1*10		840	27	40
15	VVGnon-combustible(A) - LS 3*10		840	36	195
16	VVGnon-combustible(A) - LS 5*4		840	25	240
17	VVGnon-combustible(A) - LS 5*1,5		840	26	305
18	VVGnon-combustible(A) - LS 3*1,5		840	6	334
19	VVGnon-combustible(A) - LS 3*4		840	7	334
20	VVGnon-combustible(A) - LS 5*10		840	5	519

As a result of this test, all conductive cores of the cable samples were destroyed. It was found that the third and fourth groups of cable lines are the most effective.

The effectiveness of the third group is achieved by installing a special support tray, which protects the cable line from direct flame exposure, as well as installation of cable products such as "FRLS", which means that the insulation and cable sheathing is made of plastic that is flame-retardant and emits little harmful substances. In cable samples VVGnon-combustible(A) - FRLS 3*1,5 conductors burned at 565 and 717 seconds, and in cable samples VVGnon-combustible(A) - FRLS 3*10 at 1736 and 2004 seconds respectively. We can conclude that the thicker the core of the cable sample, the higher the time of performance of the cable product if we compare cables of the same brand, but with different cross-sections. However, mounted metal tray bent relative to its axis, which means that we need additional fasteners in the form of perforated tape in 3 places as mounted in the fourth group (Figure 14.). In the fourth group of cable lines efficiency was achieved by installing a special support tray, which protects the cable line from direct flame exposure, as well as the by installation of structural fire protection (ceramic fiber) on a bundle of 7 cable samples. Analyzing the test table, we can see that the time of destruction of conductive cores also directly depends on the thickness of the cores themselves - 1.5 mm² cores burnt up to 845 seconds, 4 mm² cores burnt up to 881 seconds, and 10mm² cores - up to 1377 seconds. The metal tray fixed in 3 places with perforated tape and studs has not changed its design position.

4 Conclusion

In this paper the parameters of fire resistance and performance of cable products under the influence of flame depending on the type of cables and the method of their installation were studied.

In the process of studying the theoretical and practical parts of laboratory research detailed methods of testing for each of the experiments were developed. The technique includes a description of the test equipment, the process of sample preparation, step-by-step testing, as well as evaluation of the results.

In the practical part of this study, experiments were conducted on each of the three methods of laboratory testing, which were determined in accordance with the objectives. Each test was to identify and determine the parameters of cable products performance, namely:

- in the first laboratory test, satisfactory results were obtained, as cable samples VVGnon-combustible(A) - FRLS meet the requirements of the current GOST IEC 60331-21-2011: with a duration of fire exposure of 75 minutes, voltage was applied to the cable during the entire test.

- all cable products, which were tested in the 2nd experiment, successfully passed the laboratory tests, as the value of flame spread on the samples was less than 2.5 meters.

- In the third test, the most efficient cable lines were identified. Efficiency in this case was reached by means of variation of various kinds of cable products, the way of installation of fastenings and lining, as well as by possibility of constructive protection of cable products.

In the process of laboratory tests the direct dependence of the influence of the cable core cross-section on the preservation of the cable line operability under fire effect was revealed. That is, the thicker the core of the cable sample, the longer the operating time of the cable line under fire exposure.

Also, the third laboratory test showed more effective parameters for the preservation of operability under fire exposure in the case of bunch wiring, as opposed to single wiring, namely, the time of operability under fire exposure for the bunch is much higher than with a single cable.

Unfortunately, the results of tests for fire resistance of cable products in a single wiring according to GOST IEC 60331-21-2011 and in a bunch wiring according to GOST IEC 60332-3-22-2011 can not be extended to the results of tests according to GOST R 53316-2009 for the preservation of serviceability of cable lines, as the declared time of fire resistance of cable products - 90 minutes does not apply to the time of fire resistance of the cable line. Often, the manufacturer guarantees the maintenance of the cable line during the time specified in the certificates for cable products. However, the documentation specifies the allowable time of fire exposure when assessing the fire resistance of the cable in a single or bunch wiring. Therefore, it should be understood that the assessment of fire resistance and performance of the cable and the cable line is carried out according to completely different testing methods.

Safety design of cable lines and subsequent installation is an integral part of integrated safety of construction of buildings and structures, as well as their further operation.

The results and conclusions of this research may serve as a basis for the design of cable lines and electrical installations, drafting technical documentation and specifications.

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